Geology and Geomorphology of Seven Mile Creek Park

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Abstract

Seven Mile Creek in Nicollet County, Minnesota is fed by a network of steep ravines as it enters the Minnesota River near Seven Mile Creek Park. The history of ravine development and its relationship to base level changes on the Minnesota River and its ancestral River Warren is of interest to land managers in south-central Minnesota. This project creates the first geologic map of Seven Mile Creek Park. Mapping reveals three terrace levels along Seven Mile Creek in the park, suggesting a strong relationship between terrace development and the lowering of local base level, the Minnesota River or its ancestral River Warren. The ravines possess colluvial shelves that correlate to the terrace levels, indicating that the ravines were active during these earlier development stages of the creek. This geologic map lays the foundation for a more developed understanding of the regional geology and provides an information base for others to conduct work within the region.

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I would like to thank all those who contributed their help and guidance for this project. Dr. Chad Wittkop of Minnesota State University Mankato for helping me begin field work and giving me the idea to map the terrace levels. Thanks to Dr. Laura Triplett for assistance throughout the project with field work and working with the computer program ESRI ArcMap 9.2.1. Thank you to Dr. James Welsh for help in developing this project and his input throughout the length of the project. Thank you to Dr. Julie Bartley for input throughout the project especially with the writing.

I would like to thank the Gustavus Adolphus College Geology Department for providing me with adequate tools for fieldwork, and a computer equipped with ESRI ArcMap 9.2.1.

Thank you to my parents for granting me the gift of life and all of the opportunities that led me to develop into who I am today. All the years spent at state parks and on camping trips played a key role in developing an interest in the natural world, an interest that ultimately led me to geology.

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Introduction

Geologic maps are fundamental scientific tools that show the distribution of geologic material. The relationships between geologic materials on a map provide clues about the sequence of events that occurred in the history of the mapped region. In addition to unraveling the history of the region and understanding natural geologic and geomorphic change through time, humans can improve their stewardship of the earth through informed agriculture, construction, and other environmentally conscious practices. With a deeper understanding of geologic processes, humans can work toward achieving a higher quality of life and sustainable economic vitality.

The Minnesota River is the largest river in southern Minnesota; it flows into the Mississippi River in St. Paul. The river has a meandering channel that is incised deeply within a broad valley that is up to five miles wide and 250 feet deep. The valley was originally carved into the hummocky topography of south-central Minnesota by the glacial River Warren. At the end of the most recent glacial interval, Glacial Lake Agassiz contained enormous volumes of glacial meltwater, trapped against the retreating ice sheet to the northwest (Ojakangas and Matsch, 1982). When the moraine dam containing the lake failed, the release of water carved a channel and created the Glacial River Warren. Glacial River Warren is the ancestor of the Minnesota River. Over time Glacial River Warren and its tributaries carved through till into bedrock, creating a wide channel and associated floodplains (Johnson, 1998). Terraces composed of sand and gravel are remnants of former floodplains; they manifest geomorphically as step-like features at the edges of river valleys. Because base level dropped as the river incised its valley, high terraces are typically older and the youngest terraces have lower elevation and sit close to the modern river channel.

In the beginning stages of valley formation, numerous new tributaries formed by incising the valley wall at points of lower relief or low material resistance to erosion. As increasing amounts of water flowed down tributary streams, headward erosion lengthened the ravines upstream, eventually developing new tributaries and ravines. As local base level created by the glacial River Warren dropped, these tributaries would similarly have cut downward, leaving terraces at the edges of their paleochannels. Seven Mile Creek, which enters the Minnesota River in Nicollet County, is such a tributary stream. The steep-walled stream valleys and tributary ravines suggest that Seven Mile Creek may have geologic and geomorphic features that link it with base level changes in the Minnesota River valley.

More recently, human alteration of the landscape has changed how water and sediment move off the land surface and into streams like Seven Mile Creek and the Minnesota River. Many of the watershed areas that are tributaries for the Minnesota River have had their wetlands filled in to allocate this land for agricultural use (Yuan, 2008). Normally these wetland areas and the plants that inhabit them absorb and retain excess water and trap sediment, lowering the total discharge and sediment load of the Minnesota River. Wetland removal causes runoff to flow more directly to the river, increasing the amount of water that enters the river. Increased discharge increases the carrying capacity and the ability of the river to erode. The decrease in wetland area has caused an increase in erosion throughout the Minnesota River Basin. Land use changes such as these may contribute to accelerated ravine development and downcutting in tributary streams. Additionally, the increase in agricultural land and current farming practices has led to transport of excess nutrients to water bodies, contributing to water quality decline and negative ecological consequences such as eutrophication (Tilman, 2001).

Due to this nutrient increase, the Minnesota River currently does not meet water quality standards in many places. In particular, the Minnesota River has a high level of total suspended solids (high turbidity), and high concentrations of nitrates and phosphates (Engstrom, 2009). Suspended solids make the water turbid, and can increase the water temperature by absorbing the sun's heat. The warmer water may be unsuitable for the plant and fish species that naturally inhabit these waters. Very high levels of suspended solids can foul fish gills and suffocate fish. Additionally, suspended solids can be organic particles, which can decompose in the water, resulting in the consumption of dissolved oxygen due to biochemical oxygen demand, with potentially detrimental effects on aquatic life.

The Minnesota River watershed is very large, with many complex processes contributing to its development, but by studying tributary watersheds we may gain important insights into factors influencing the river system as a whole. Seven Mile Creek Park is a Minnesota public park, located in Nicollet County and can be found between St. Peter and Mankato along US Highway 169 (Figure 1). This public park forms a small portion of the Seven Mile Creek watershed. Within the Park there is an extensive network of ravines, which may contain geologic features that record the events that controlled their formation.

Seven Mile Creek Park and its ravines in Seven Mile Creek Park will shed light on the factors that control downcutting, ravine development, and sediment transport in this tributary to the Minnesota River. Mapping the geology and geomorphology of Seven Mile Creek and its ravines in Seven Mile Creek Park will shed light on the factors that control downcutting, ravine development, and sediment transport in this tributary to the Minnesota River. In particular this

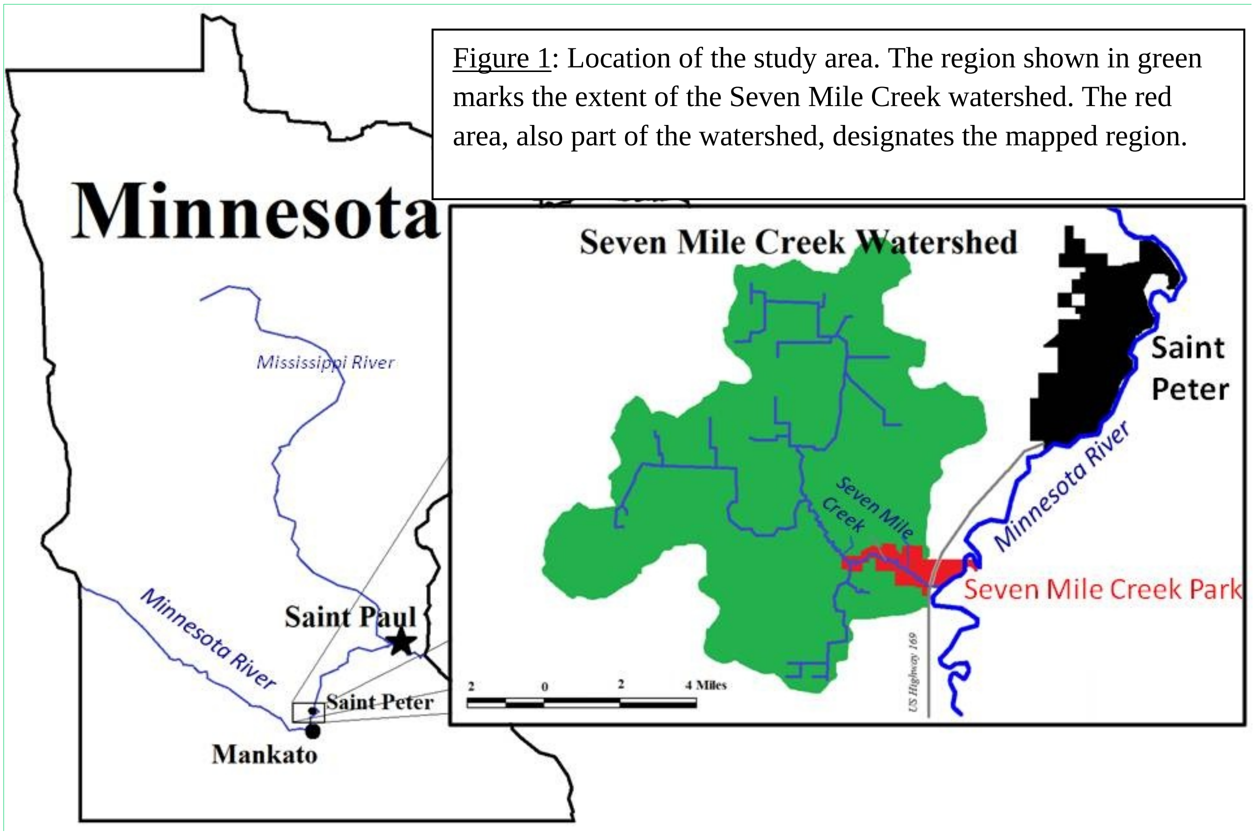

Figure 1: Location of the study area. The region shown in green marks the extent of the Seven Mile Creek watershed. The red area, also part of the watershed, designates the mapped region.

geologic map will 1) help constrain the relative roles of post-glacial base level change and more recent land-use changes; 2) provide information that can identify and help reduce erosion hazards within the park and identify sediment sources that could be contributing to the turbidity of the Minnesota River; 3) provide information to assist decision makers in their effort to improve and sustain the natural ecology within the Seven Mile Creek watershed and all other organisms downstream that are affected by the poor quality of water that currently leaves this region. With a greater understanding of the past, decision makers will be better equipped to make choices for the future of Seven Mile Creek Park.

Geologic Setting

In south-central Minnesota, where Seven Mile Creek Park is located, Early Paleozoic bedrock underlies Cretaceous and Pleistocene strata. The Paleozoic sedimentary rock includes the Jordan Sandstone, Kasota Sandstone and Oneota Dolomite. Runkel (1994) divides the Cambrian-aged Jordan Sandstone into four lithofacies: (1) a very fine-grained, hummocky cross-stratified burrowed sandstone; (2) a fine-grained, trough cross-stratified, burrowed sandstone; (3) a medium- to coarse-grained, large-scale cross-stratified sandstone; and (4) a heterolithic unit comprising, thinly-interbedded sandstone, mudstone, and shale. According to Runkel (1994) the Mankato area has only lithofacies (1) and (2). The Lower Ordovician Kasota sandstone overlies the Jordan Sandstone. This unit varies from a few inches to six feet in thickness and is composed of white, medium to coarse, well rounded sand grains (Powell, 1935). The Kasota sands were apparently derived from the underlying Jordan sandstone. The Kasota Sandstone cannot be distinguished from the Jordan except for the presence of Ordovician index fossils that are quite foreign to any belonging within the Jordan. The Kasota Sandstone is known only at Kasota and St. Peter along the Minnesota River (Powell, 1935). The Ordovician-aged Oneota Dolomite overlies the sandstone units and is thick-bedded, drab to buff, and in places pink, and may be sandy or shaly (Stauffer and Thiel,1934). The thickness of the formation varies greatly, from about 20 feet in St. Peter to 150 feet at Dresbach. Even greater thicknesses occur in the region of Albert Lea and Austin. Along the western margin of the Paleozoic rocks, to the north and south of Mankato, the Oneota is seldom seen at the surface but exists beneath the drift, or it may be covered by the basal beds of the Cretaceous (Stauffer, 1934). Mark Johnson, a former Gustavus Adolphus Professor, believes that the Oneota Dolomite is absent at the park. Johnson cites rivers that cut through the region prior to the Pleistocene glaciation as the likely cause of erosion process that removed the dolomite.

According to Matsch (1972), four lithologically distinctive till units occur within the Minnesota River Valley. These four till layers are commonly referred to as the Old Gray Till

(100 ka), the Hawk Creek Till (35 ka), the Granite Falls Till (34 ka), and the New Ulm Till (12 ka). Each glacial unit corresponds to a distinct ice lobe that passed through the area during the Wisconsonian glaciation.

Seven Mile Creek Park also contains several types of sediment laid down by post-glacial processes. The creek has floodplain sediments. Several of the ravines have variously sized alluvial fans, and many steeper slopes have lost soil and regolith to mass wasting to create reworked unconsolidated sediments.

Methods of Study

The majority of data came from fieldwork and observations made at outcrops and landforms within the Park. Information was gathered in a field notebook and recorded on field base maps. These base maps are contour maps that are derived from Light Detection And Ranging (LiDAR) data taken by Brown-Nicollet Counties in 2008. LiDAR data was imported by ESRI ArcMap 9.3.1 and reformatted to yield detailed contour maps. The base maps were printed at scales between 1:2000 and 1:3600. At the park, the elevations of the contact between the Jordan Sandstone and the glacial till units were observed and recorded on the base map and in a field notebook. Most elevations were obtained from the detailed base maps and a few elevations were checked by surveying methods. Throughout the park, alluvial fans and terraces were found and their location and extent was recorded on the base maps. Their extent was determined by the transition from clay and silt particles to the presence of topsoil. After the fieldwork was complete, maps were constructed using ESRI ArcMap 9.3.1, and the recorded data was used to construct polygon shapefiles that correspond to the geologic and geomorphic units. Each unit has a distinctive polygon layer. Once the initial field data was input into ArcMap, additional terrace regions were interpreted based on their similar appearance to known terrace structures in

ArcMap. These areas where the interpretations were made were covered with vegetation and their true structure was undistinguished in the field.

Depth to bedrock, elevation of bedrock unit, and type of bedrock data was found from 20 well logs using the Minnesota county well index data system. The County Well Index data system was developed by the Minnesota Geologic Survey and the Minnesota Department of Health.

Unit Description

The map produced, (Appendix A) differs slightly from traditional geologic maps in that it has both geologic and geomorphologic units on the map. If the map contained just geologic units the map would have simply been bedrock, glacial till, and alluvium omitting the presence of terraces and colluvial shelves (described below). Geologic units were distinguished based on their lithology, while the geomorphologic units were distinguished based on their shape and elevation. Both units display the story of the development of the park.

Geologic Units

The only bedrock unit exposed in the park is the Jordan Sandstone. The Jordan that is visible is generally a fine-grained, trough cross-stratified, burrowed sandstone. At the majority of outcrops, bedding planes are difficult to see due to liesegang banding (Figure 2). The sandstone is weakly cemented.

Glacial till is light brown in color and has a high sand component. The till is loose, unconsolidated material that is mostly sand, silt, and clay with pebbles of various sizes mixed throughout. Individual glacial units were not distinguished in this map.

Geomorphic Units

The floodplain is the area that is covered by flood water in a typical year. It is relatively flat and consists of sandbars immediately adjacent to the channel.

Terrace level 1 is a flat surface near the river that has a maximum elevation of zero to one meter above the floodplain of the Seven Mile Creek.

Terrace level 2 is a flat surface near the river that has a maximum elevation of one to three meters above the floodplain of the Seven Mile Creek.

Terrace level 3 is a flat surface near the river that has a maximum elevation of three or more meters, reaching a maximum height of 18 meters above the floodplain of the Seven Mile Creek (Appendix C).

Colluvial shelf 2 is a flat surface in a tributary ravine that is one to three meters above the base of the ravine.

Colluvial shelf 3 is a flat surface in a tributary ravine that is three or more meters above the base of the ravine.

Alluvial fans are ravine outwash material found at the mouth of the ravine. They contain larger sediment nearer to the mouth of the ravine and their outer reaches have silt and clay sized particles. They typically form fan-shaped structures and may overlap or merge with terraces. The edges of alluvial fans may be reshaped by erosion.

Holocene Colluvium is characterized by the slumping and mixing of the till with surface soil. This unit is typically unsorted and unconsolidated.

Undifferentiated material is represented by recent slump material or sediment that has been reshaped by human activity, such as bulldozing.

Results

The Jordan forms the sandstone bluffs in the park. These bluffs, which can be as much as 12 meters high, extend throughout the picnic and parking area. Along these bluffs, the sandstone is often covered with loose, unconsolidated material that limits the Jordan sandstone exposures, especially on the bluffs on the south side of the creek (Figure 3). The Jordan Sandstone exposures on the south side may be less than one meter in both height and width, but are commonly found at similar elevations to one another, making them more reliable to map. Sandstone is not seen until the creek exposes it again, a half mile past the parking area along the hiking trails. In these exposures the sandstone is anywhere from two to five meters above the creek bed. The Jordan is exposed in some of the ravines. In the lower ravines the exposures are similar to small scale bluff features, but in two of the upper ravines the Jordan sandstone has an upper layer that is more resistant to weathering. These resistant layers are preventing the downcutting in the ravines, but the loose underlying

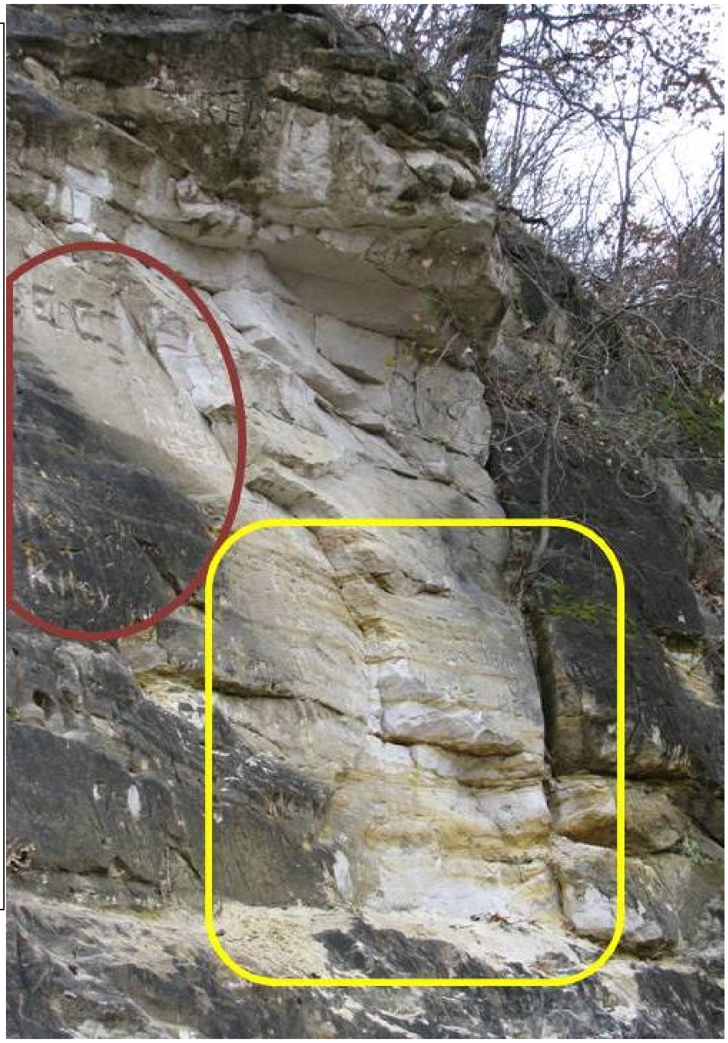

Figure 2: A Jordan Sandstone outcrop with liesegang banding (yellow box), making the bedding seem horizontal, when in fact it is cross-bedded. The Jordan is weakly cemented making it an easy target for graffiti (red circle). The black material that covers this outcrop is the topsoil that has been washed down the rock face.

sandstone is eroded away more easily (Figure 4) This more resistant layer could be described as orthoquartzite. The layer is not quartzite, the grains are still visible.

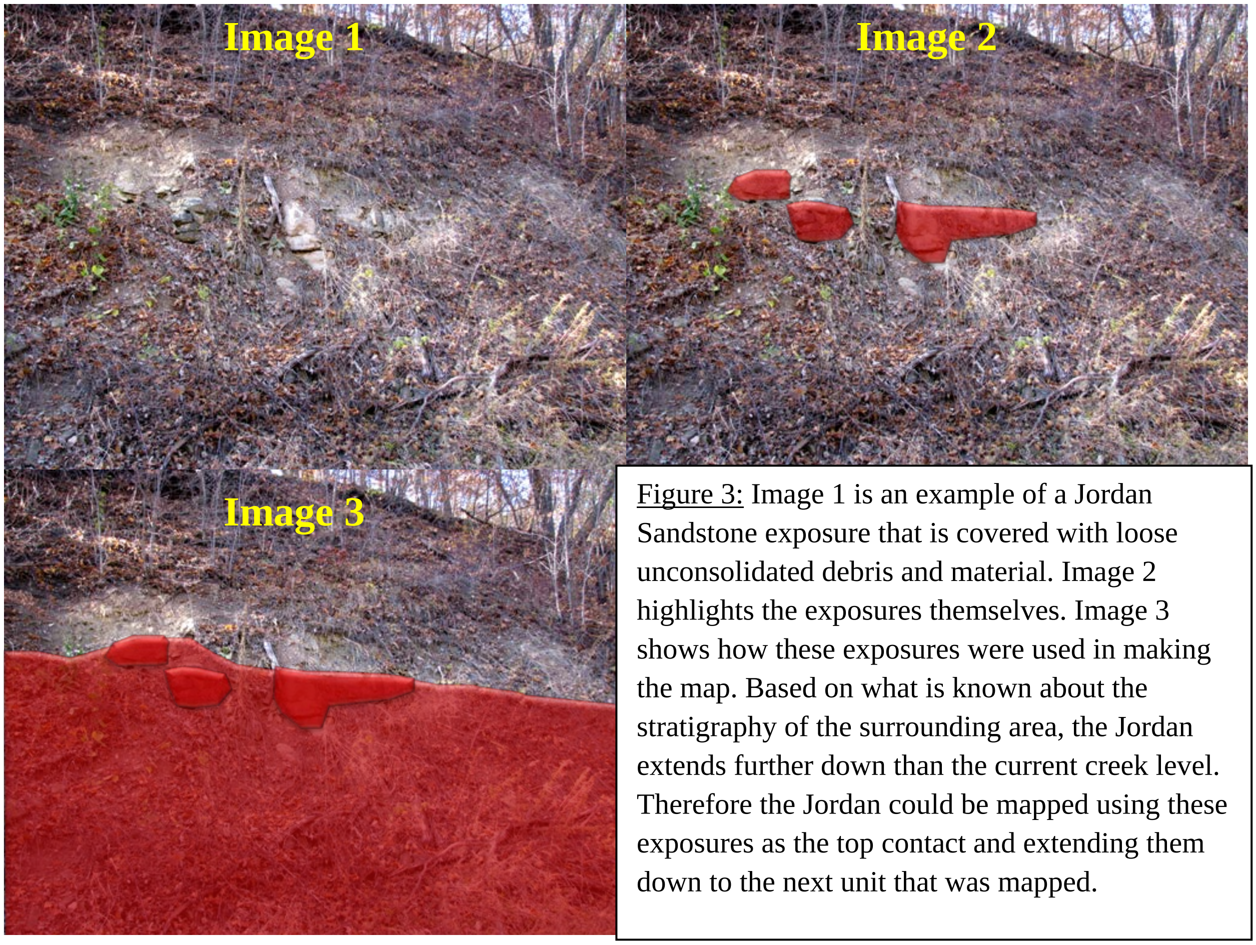

Figure 3: Image 1 is an example of a Jordan Sandstone exposure that is covered with loose unconsolidated debris and material. Image 2 highlights the exposures themselves. Image 3 shows how these exposures were used in making the map. Based on what is known about the stratigraphy of the surrounding area, the Jordan extends further down than the current creek level. Therefore the Jordan could be mapped using these exposures as the top contact and extending them down to the next unit that was mapped.

Throughout the park there is no definite evidence suggesting the presence of the Oneota Dolomite. The Jordan Sandstone contacts are covered with till. There is a site near Kirby Pass that presently consists of regolith. This regolith is too weathered to identify without more advanced methods (Figure 5). This site is near the elevation above the Jordan that the Oneota is known to exist outside of Seven Mile Creek Park. Further work would be needed to confirm or refute the presence of dolomite within the park. This regolith may be Cretaceous. The Cretaceous rock in the area around St. Peter is not very well understood. In any case the rock is too weathered to identify in hand sample.

Figure 4: A meter high knickpoint waterfall in an upper ravine. The ephemeral stream flows over a more resistant orthoquartzite layer that is present in the upper Jordan Sandstone.

Figure 5: The image on the left is a close up view of a small regolith outcrop that is difficult to identify. The leading hypotheses are that it was either dolomite or cretaceous rock. The image on the left is the same rock only broken open to remove the surficial weathering.

The Glacial till can be seen in outcrops in the ravines.

In the area surrounding Seven Mile Creek, there were only 21 wells with data information. Of these 21 wells only 20 of them contact bedrock. Figure 6 shows the well distribution and first contacted bedrock. From the well information we can gather that the Jordan

Sandstone terminates somewhere within the area of the creek. The Jordan sandstone is present at a higher elevation, yet the wells to the east contact bedrock at a lower elevation suggesting that the Jordan was somehow eroded away in this area.

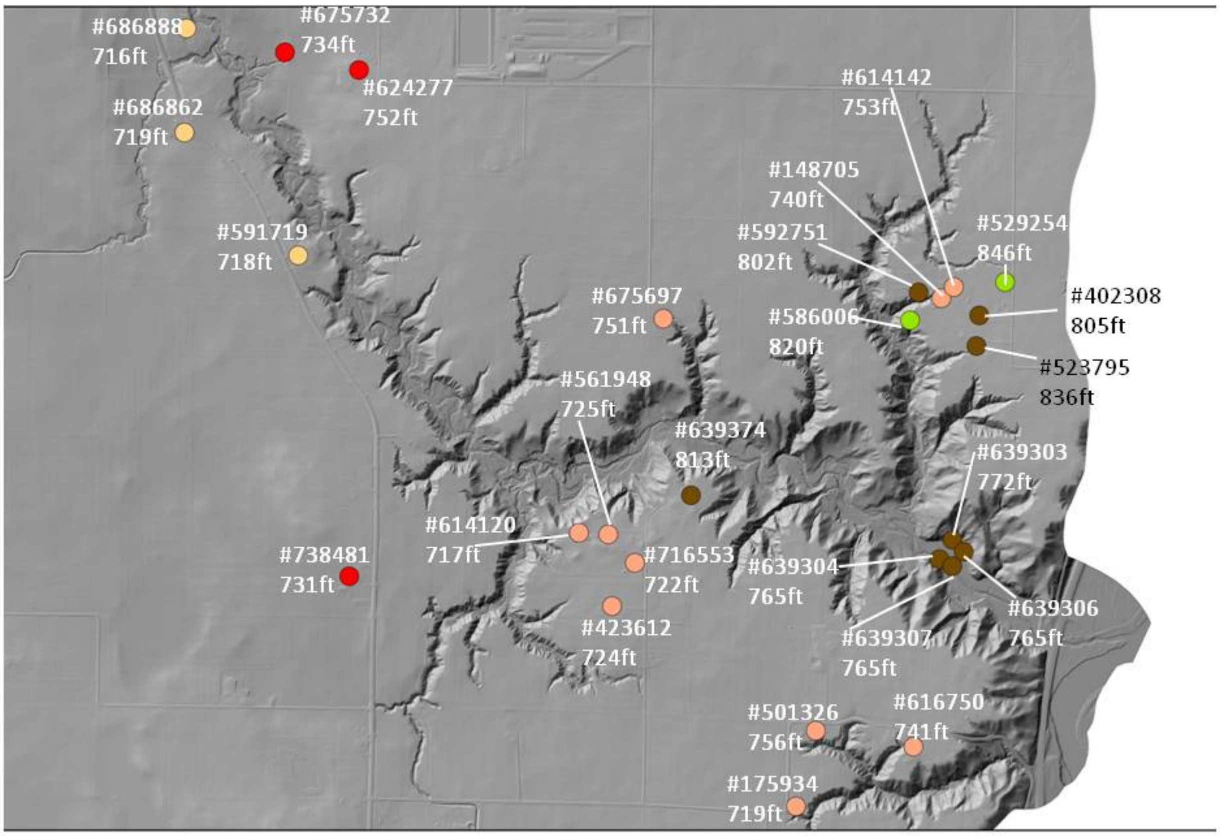

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Figure 6: The distribution of the wells with data. Each well has its unique well number displayed as well as the elevation in feet of the first bed rock contacted (for reference the flat surface is approximately 965ft). The colors of the circles display the specific rock unit. Yellow = Franconia, Red = St. Lawrence, peach = St. Lawrence-Franconia, Brown = Jordan, Light green = Cretaceous (Note both cretaceous sites are underlain by at least 60ft of Jordan Sandstone)

Geomorphologic Units

At Seven Mile Creek, the current floodplain lies within the larger channel that now contains it. During the summer the upper reaches of the creek lose water to the groundwater system, leaving a dry creek bed until the lower reaches on the creek. In the lower reaches of the creek, the creek is recharged by the groundwater system.

Following along the creek and bluffs, terraces occur numerous times in the stream valley can be seen (Figure 7). Along the bluffs there are largest terraces that range anywhere from 3 to 18 meters above the floodplain. Many of these larger terraces have deposits from hill slumps or alluvial fans on top of them. These terraces tend to be heavily vegetated, making them difficult to identify. There are two distinct terrace levels that can be seen near the creek one tends ranges in height above the floodplain. The higher of the two levels ranges from one to three meters above the floodplain, while the lower level ranges from zero to one meter above the floodplain. More of the lower level terraces are present in the upper reaches of the park, especially around the area where the park’s largest ravine stream meets the creek.

Seven Mile Creek Park has many ravines, each with their own set of characteristics. These ravines range in overall length, channel height, erosion rates, number of streams that feed into them, some are drain tile feed, many have fallen trees in them, and some have the presence of a bedrock ledge. These bedrock ledges are composed of a more resistant orthoquartzite sandstone layer that causes knick points within the ravines. In some ravines the fallen trees dam the streams, causing the water to reroute from its straight path. In longer ravines the streams have developed meanders near where they meet the creek. A few ravines have alluvial fans that may align with terraces on the other side of the creek. The water flow in all of the ravines tends to be more ephemeral and is manly feed by precipitation events. The longer ravines tend to have water in their channels for longer periods of times. In many of the ravines there is new down cutting taking place, leaving terrace like structures, colluvial shelves, on the sides of the ravines.

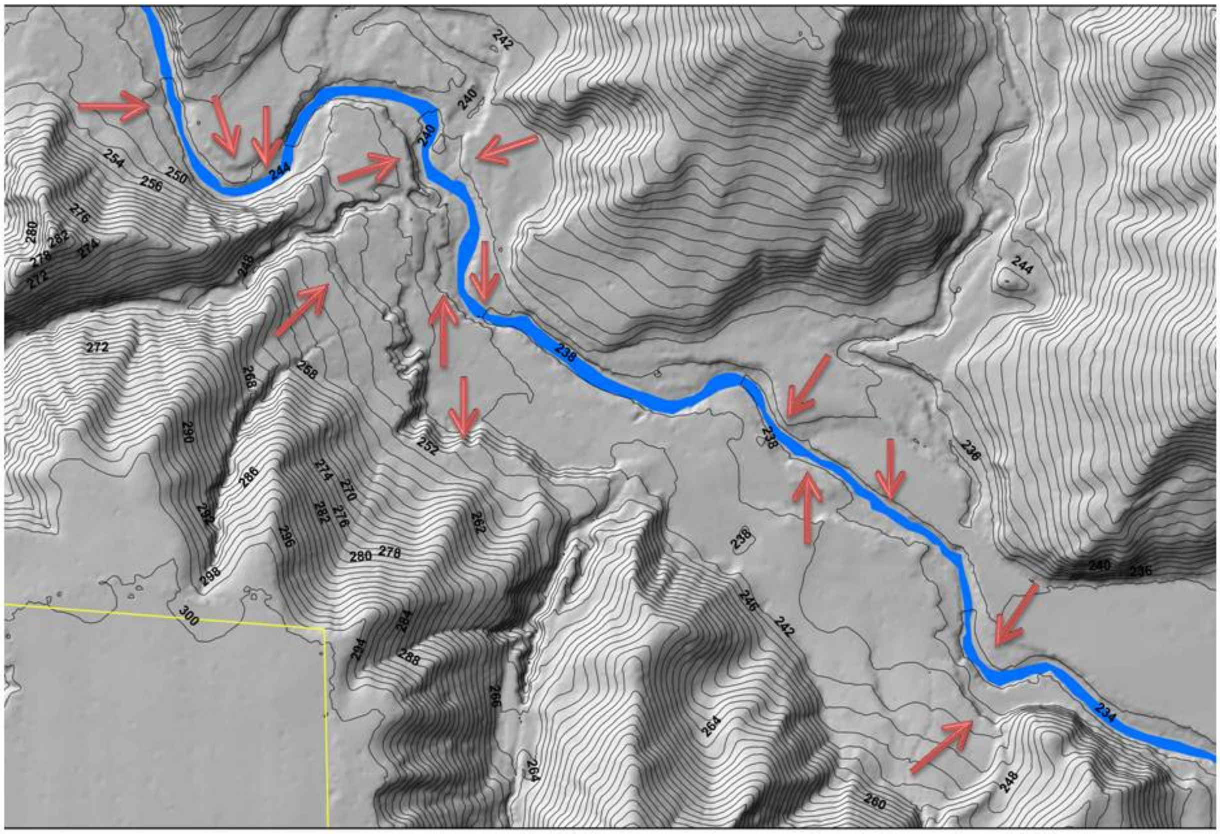

Figure 7: The presence of terraces can be seen in the middle section of the park, the Creek is shown in blue, the yellow line represents the park boundary, the contour lines are drawn every 2 meters and the red arrows point to many of the different terraces that are made visible by the ArcMap.

All of the bluffs, ravines, and hillslopes are covered with a thin layer of reworked soil and till (usually .5-1 m thick), except where sandstone or till can be seen in outcrop. This material has been reworked due to erosional surficial processes and can be from slumps.

Discussion

The numerous terraces present within the area surrounding Seven Mile Creek suggest that the steam has gone through many periods of downcutting. The question arises, when did these periods of down cutting occur and what factors controlled them? One hypothesis is that Terrace Level 3 reflects a higher base level that existed as Glacial River Warren was still carving the valley shortly after deglaciation. A terrace with a height of 18 m is significantly higher than modern levels, and the extensive amounts of sediment deposited in alluvial fans and colluvial shelves could indicate a long period of deposition. On the other hand, a second scenario is that after Glacial River Warren was gone, the stream could not immediately respond with downcutting because it was stranded on a resistant bedrock ledge. The existence of the more resistant orthoquartzite layer in two of the ravines and along one section of the creek supports this hypothesis. These observations suggest that bedrock may indeed cause a lag between change in base level and a stream or ravine's ability to respond.

In either case, these high terrace levels and apparently older alluvial and colluvial depoists indicate that recent human changes to the landscape such as ditching, tiling and wetland destruction, are not the sole reason for erosion in Seven Mile Park. Specifically, the fact that colluvial shelves in some ravines correspond to Terrace Level 3 in the Seven Mile Creek valley indicates that those ravines were actively eroding and depositing long ago. Some have suggested that building ditches and draintile is the primary cause of ravine development and sediment erosion in south-central MN. The addition of draintile to the heads of some ravines in the park has likely increased the amount of sediment eroded from ravines in recent years, but again, the ravines themselves are not entirely recent additions to the landscape.

The well data suggests that some process removed lots of bedrock allowing for a greater amount of till to be deposited to the north and east of the park. The same process that removed this bedrock could play a role in the missing Oneota Dolomite.

Conclusion

The base level changes are recorded in the three different terrace levels. The factors controlling their development remain unknown. The presence of terraces 18 meters (Appendix

C) above the current floodplain suggests one of two things: either they formed before the modern Minnesota Valley or that there was a bedrock knickpoint that prevents further downcutting, allowing these terraces to form. The presence of colluvial shelves in the ravines that correlate to terraces, indicate that the ravines were active at a much earlier time. We also know that by the fact that alluvial fans are cut by terraces that the fans formed first, therefore those ravines were active prior to the downcutting.

Future Work

Overall, this mapping project lays the foundation for a more developed understanding of the regional geology. More work is needed to understand how the terraces relate to each other. Detailed plots of stream profiles would be most informative in understanding how the development of ravines correlate to one another. More work in the park could be done on the regolith site to confirm or reject the presence of dolomite. The presence or absence of dolomite at this site is key to understanding the pre-glacial processes in shaping regional geologic history. Geochronology of the ravines and terraces would lend insight into their development. Knowing when the ravines developed would allow us to calculate rates of erosion. If the ravines are young, they are eroding at a substantially faster rate than previously thought. Once the controls are better understood, finding a way to increase the water quality of the Minnesota River will hopefully be more effective.

Other work that would inform us on the park's history would be to map the individual till layers. A project dealing with just the tills would be extensive. The number of actual till outcrops within the park is minimal and knowing how they change throughout the landscape is made difficult by the substantial amount of till that has been eroded away or reworked into other deposits.

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